FINAL PERFORMANCE REPORT

THE UNIVERSITY OF ARIZONA
COLLEGE OF AGRICULTURE & LIFE SCIENCES
Yuma Center of Excellence for Desert Agriculture

Arizona Grain Research and Promotion Council

Project Title & number	**Water and Salt Balance for Durum Wheat Irrigation (17-03)**
Project Timeline	October 1, 2016 – September 30, 2017
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Abstract

Studies were conducted in 2016-2017 to evaluate water and salt balance during a lettuce-wheat rotation. Funding from the AGRPC was used to collect data during the Durum wheat component of this rotation. We only had two Eddy Covariance (ECV) systems to measure evapo-transpiration (ET) in 2016-2017, so only two sites could be fully instrumented to quantitate water and salinity balance. A third site was used to monitor changes in soil salinity during the wheat crop. The data show that ET for Durum wheat ranged from 590 to 646 mm. These data are consistent with previous work and show that the vegetable component of the crop rotation was generally net salt loading in the crop root zone. Interestingly, for two of the three wheat sites, there were also more total salts in the surface soil layer after wheat than before. The one field site where there was a net leaching of salts during the wheat production period was a coarse textured soil. Analysis of the cations and anions in soil extracts suggests that precipitation and dissolution reactions with carbonate species likely complicated estimates of leaching fractions estimated using the steady state mass balance approach with total salinity. However, we found no evidence of chloride (Cl) precipitation, suggesting Cl ratios can be used to estimate the leaching fractions achieved. The use of Cl ratios as a conservative tracer suggests the leaching fractions from the surface soil ranged from 8 to 20% during wheat production, the high value associated with the coarse textured soil. However, leaching fractions less than 20 would not be sufficient to relieve the salt burden accumulated during the vegetable-wheat production periods of the cycle. These data suggest the pre-irrigation event in late summer before vegetable production may be of paramount importance for restoring salt balance in many vegetable-wheat

production systems. We obtained additional ECVs for deployment in 2017-2018 and will focus on expanding data collection for vegetable-Durum wheat rotations.

Introduction

Water and salt management are of paramount importance to agricultural sustainability in the lower Colorado River region near Yuma. Because the irrigation water has salts, and because the shallow ground water in the valleys that fluxes up through the fine textured soil by capillarity has salts, some level of excess irrigation (beyond crop consumptive use) must be applied to leach salts below the crop root zone. Effective leaching is especially important in this region because many of the crops produced are sensitive to salinity.

Crop production systems and rotations in the lower Colorado River region of Yuma utilize a number of irrigation application methods over the cropping season. The systems utilized and the management of these systems can have a profound impact on water delivered, leaching achieved, and resulting salt distribution. It has been shown that irrigation efficiencies during the vegetable production portion of the rotation are very high (Sanchez et al., 2008) and this component is often net salt loading because leaching fractions achieved are often less than the leaching required to maintain salt balance.

Durum wheat is a crop commonly rotated with cool season vegetables. Durum wheat produced in the desert is established (germinated) by either planting into the soil moisture (shortly after an irrigation), sprinkler irrigation after seeding, or by basin surface irrigation after seeding. After stand establishment all wheat is irrigated by basin surface irrigation. Paramount to efficient irrigation management is accurate estimates of ET and the tools to use these estimates. Irrigation time is determined by the allowable depletion of available water within the soil profile to avoid yield loss, and the required depth is determined by the amount required to refill the water lost from the soil profile by ET.

The depletion of soil moisture by crops can be measured directly by soil sensing devices or estimated from weather-based ET measurements. Where ETc is calculated from ETo and crop coefficients (kc), and ETo is calculated using weather based equations (eg.Penman Monteith or others). Over the past decade there have been significant advances in technologies to measure crop ET under field conditions. One such technology is Eddy Covariance (ECV). Eddies are turbulent airflow caused by wind, the roughness of the Earth's surface, and convective heat flow at the boundary between this surface and the atmosphere. ET occurs when water vapor in upward moving eddies is greater than in downward moving eddies. Sensible heat is positive when upward moving eddies are warmer than downward moving eddies. Water vapor, heat, and carbon dioxide transferred by eddies can be measured directly using ECV. The ECV method is now a well-established, standardized, and state-of-the-art approach for measuring ET and results from ECV stations are considered reference quality. The objective of these studies was to quantitatively track water use and salt balance across lettuce-wheat rotations in the lower Colorado River region.

Materials and Methods

These studies were conducted at two sites used for lettuce-wheat rotations. One was in the Yuma Irrigation District (YID or South Gila) and one in the Yuma County Water Users Association (YCWUA or Yuma Valley). Pre-irrigation occurred August 13, 2016 at the YID site and August 30, 2016, at the YCWUA site. The wet date for lettuce at the YID site was Sept, 28, 2016. The wet date for lettuce at the YCWUA site was Oct. 6, 2016. The wheat was planted on December 14 and January 10 at the YID and YCWUA sites, respectively. We also collected salinity data before and after wheat in a site in the Bard Water District (BWD) but in 2016-2017 we did not have the instrumentation to collect ET data for this site. This site was planted December 19.

Estimating water used by crops was accomplished by measuring evapotranspiration (ET) with an instrument system known as Eddy Covariance (ECV) (Figure 1). ECV obtains ET by measuring incoming and outgoing energy fluxes over the cropped landscape. The ECV measures four energy flux components- net radiation (Rn), ground heat flux (G), sensible heat flux (H), and latent heat flux (LE). Rn represents absorbed solar and infrared radiation, G is heat transported into the soil, H is turbulent heat above the crop due to air temperature gradients, and LE is latent heat energy due to ET. While ET can be estimated from just the LE component, accurate estimates require collecting all four components. ECV data values are reported in energy flux units (W/m^2), with water-specific quantities also reported as depths over time (e.g. mm/day).

Each ECV system requires sensors, one or more data loggers, power supplies, and mechanical supports. Sensors measure air temperature, humidity, wind speed, wind direction, water vapor concentration, CO2 concentration, soil temperatures, soil moisture, solar and infrared radiation, all at sample rates up to 20 Hz. Data loggers collect, analyze, and store analog and digital signals from the sensors; in some cases, they are connected to a cellphone modem for transmitting synopses of data and system health information to one of our home offices. Power supplies consist of 12V batteries, voltage regulators, grounding rods, and solar panels. The mechanical supports include tripods, masts, lightning rods, anchors, and guy wires to ensure the sensors, loggers, and power supplies remain accurately aligned in all weather conditions.

Along with atmospheric water measurements we tracked water applied. For sprinkler irrigation systems we used in-line meter (i.e. ESSFIFLO Ultrasonic Flowmeter) and pressure data logging instruments (i.e. Pollardwater Pres/Temp logger). For surface irrigation we used flumes with depth sensors and data loggers to measure in-flow hydrographs and water depth sensors (Troll 100 water depth sensor and logger) to measure water depth profiles in transects along the irrigation run (inlet to downstream border). Data were downloaded and processed after each irrigation event.

Each field was surveyed using a Geonics Dual-dipole EM38 meter mounted on a mobilized assessment platform with an integrated (sub-meter accuracy) GPS system, with all survey and GPS position data logged into an on-board portable computer (Figure 2). In the baseline survey, EM38 signal data was collected once every two seconds within transects spaced 10 to 20 meters apart, typically generating from 1000 to 5000 survey positions per field (transect spacing and the total number of survey positions will depend on the field size). These data were analyzed using the ESAP software package (https://www.ars.usda.gov/pacific-west-area/riverside-ca/us-salinity-laboratory/docs/esap-model/) and the spatial response surface sampling algorithm in the ESAP-RSSD program. At each sampling location, a single 1.2 m soil core was extracted using automated soil auguring equipment and split into four depth-specific 30 cm samples. The soil samples collected from each core were bagged, labeled, and subsequently used for the chemical and physical analyses.

Subsets of all soil samples were oven-dried to determine soil moisture contents. The remainder of the soil samples were air-dried prior to laboratory analysis. After obtaining saturated paste extracts from all soil samples, we determined electrical conductivity (ECe), and cation/anion quantities for Ca^{+2}, Mg^{+2}, Na^{+}, K+, Cl^{-}, $SO4^{-2}$, $NO3^{-}$ and CO3 by ion chromatography. These data were used the calculate sodium adsorption ratio which is used to access the impacts of Na on soil physical properties such as soil structure and infiltration. These cation and anion data were also used with a speciation program (MINTEQ 3.1) to gain a preliminary understanding of the chemistry of soil reactions with respect to these salinity ions. We also estimated leaching fraction (LF) using these data. This computation is based on salt balance approach where under steady state assumptions:

$$LF=Ddw/Diw=Ciw/Cdw$$

where D=volume of water, C=concentration of salt, iw=irrigation water, and dw=drainage water (ASCE, 1990). In application, the ECiw and ECdw are often substituted for Ciw and Cdw into this equation. For reasons described below we substituted the Cl concentrations of irrigation water and soil water in specific soil depths as described by others (Rhoades, 1980; Samani et al., 2005). The Cl in the saturation paste extract (Cle) was measured as noted above. The Cl concentration in the soil water (Cl_{sw}) was estimated by (Cle)(SP)/PW where SP is measured saturation percentage and PW is measured gravimetric water at the time of sampling. The concentration of Cl in the irrigation (Cl_{iw}) water was measured as noted above.

Results

Measured daily ET and seasonal cumulative ET for the YID and YCWUA sites are shown in Figures 3 and 4. These data show that wheat ET ranged from 590 to 646 mm (about 2 acre feet). Interestingly, these values are close to the total ET estimate made by Erie et al. (1982) for bread wheat and close to values Sanchez and Brown measured for durum wheat using weighing lysimeters (data unpublished).

Total soil salinity as measured by ECe, the sodium absorption ration, and the soil chloride levels at several soil depths across rotations are shown in Figures 5 and 6. Pre-irrigation did transport salts from the soil surface and into lower soil depths for the YID site (Figure 5). For the YCWUA site, there was a small reduction in the surface with a more pronounced reduction at deeper depths (Figure 6). It should be noted that the site selected in the YCWUA was very coarse textured and would be considered an outlier compared to the median textures of soils used for lettuce and wheat production. The lower depths are exceptionally sandy for the YCWUA site. Interestingly, there seemed to be a preferential leaching of Na and Cl, as reflected by the lower measured SAR and soil solution Cl values (Figures 5 and 6)

Overall, in-season irrigation application efficiencies after lettuce thinning are high, often exceeding 90%. Because lettuce irrigated with Colorado River water has a required leaching of 20%, we would not expect net leaching during the lettuce crop cycle. This was definitely the case for the YID site (Figure 5). For the YCWUA, there was leaching during in-season irrigation within the sandy subsurface (Figure 6).

Data show that for the YID and BWD sites, there were higher levels of salt in the surface soil after wheat than before wheat (Figures 5 and 7). The YCWUA site did show a reduction in total salinity during wheat production. As noted, this experimental, site was sandier than fields typically encountered and may not represent more common outcomes. Using total salinity measurements, we might conclude there was little leaching during the wheat component of the cropping rotation. However, a close inspection of the soil solution data suggests that it may be supersaturated with mineral species (Table 1). Interestingly, levels of cations and anions in the soil water are much higher than the concentration in irrigation water. The increase is especially pronounced for CO3. Plant roots and soil microbes are producing CO2 during respiration. While much of it diffuses to the atmosphere some of it goes into the soil solution affecting carbonate chemistry. These data indicate the surface soil solution was supersaturated with respect to some Ca and Mg carbonate minerals (Table 1). This may mean that mineral precipitation and dissolution reactions may complicate using the steady state mass balance approach with total salinity to estimate leaching fraction. More thermodynamic and kinetic work is needed to fully understand the chemical reactions taking place in the soil profile. This work is not on our agenda or in our budget for 2017-2018 but will be addressed in 2018-2019. Fortunately, we were not supersaturated with respect to chloride mineral species, suggesting Cl ratios might be utilized to estimate leaching fractions.

Leaching fractions (LF) estimated by Cl ratios from the soil surface during wheat are shown in Table 2. The LF were less than 10% for the YID and BWD sites but approximated 20% for the YCWUA site. These LFs achieved at the YID and BWD sites would not be adequate to maintain soil salinity levels suitable for sensitive crops such as lettuce. We also used Cl ratios to estimate leaching fractions achieved during pre-irrigation events. For the YID and YCWUA sites these data were collected prior to the 2016-2017 produce season, in the summer of 2016. For the BWD sites these data were collected after wheat and prior to the 2017-2018 produce season in the summer of 2017. These data show that the LFs during pre-irrigation were close to or exceeded 20%, indicating this pre-irrigation practice may be of the upmost importance for salt management in produce production systems. Studies conducted during the 2017-2018 season will be expanded to more vegetable-wheat rotations. During this season we will also use detailed water budgets to corroborate these preliminary findings.

Literature Cited

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Sanchez, C. A., and J. C. Silvertooth. 1996. Managing saline and sodic soils for the production of horticultural crops. HortTechnology 6:99-107.

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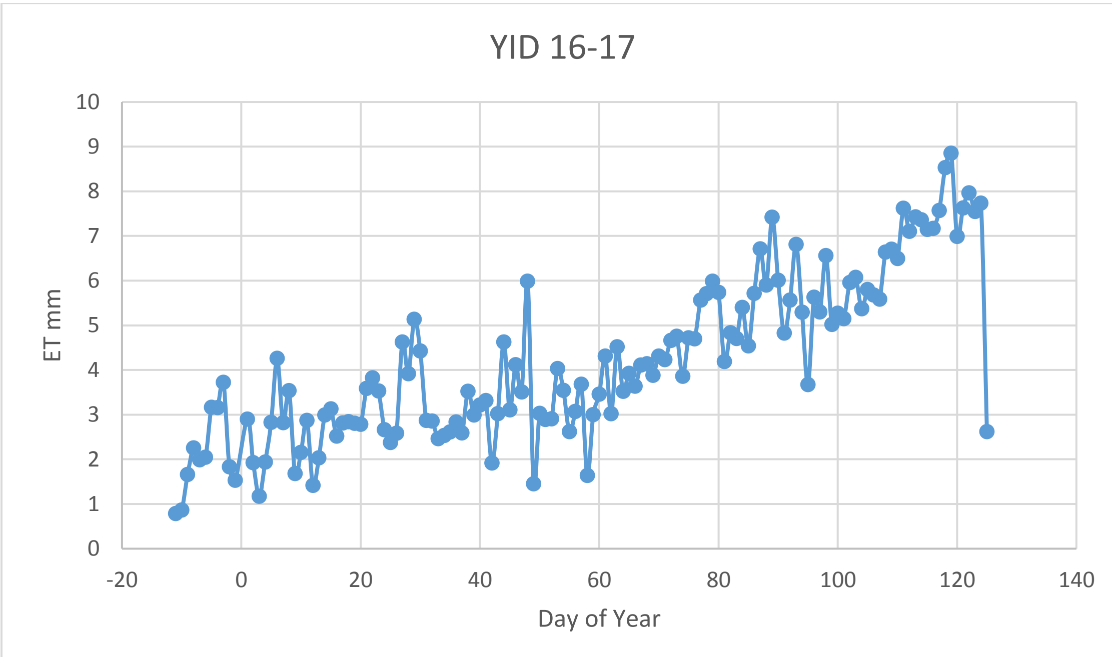
Project Photos and Data Graphics

Figure 1: Eddy Covariance systems in lettuce and Durum wheat fields in 2016-2017

Figure 2: Electric Magnetic Induction unit (EM38) used in GPS references salinity surveys

Figure 3: Estimates of daily ET (a) and cumulative seasonal ET (b) for wheat using Eddy Covariance methodology at the YID site



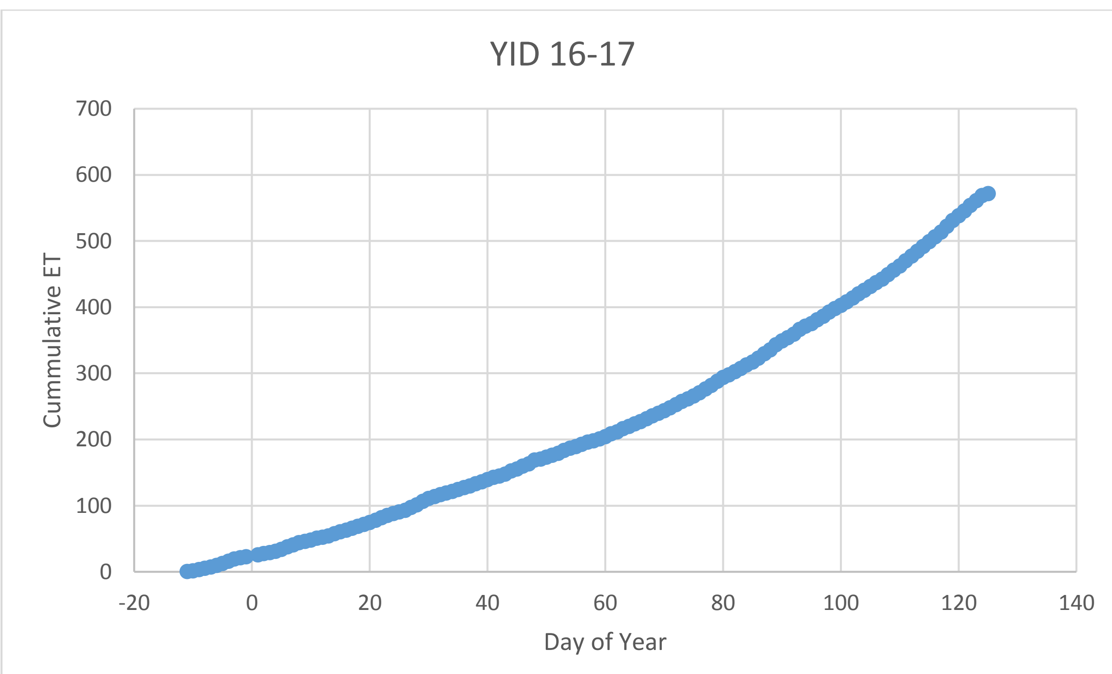
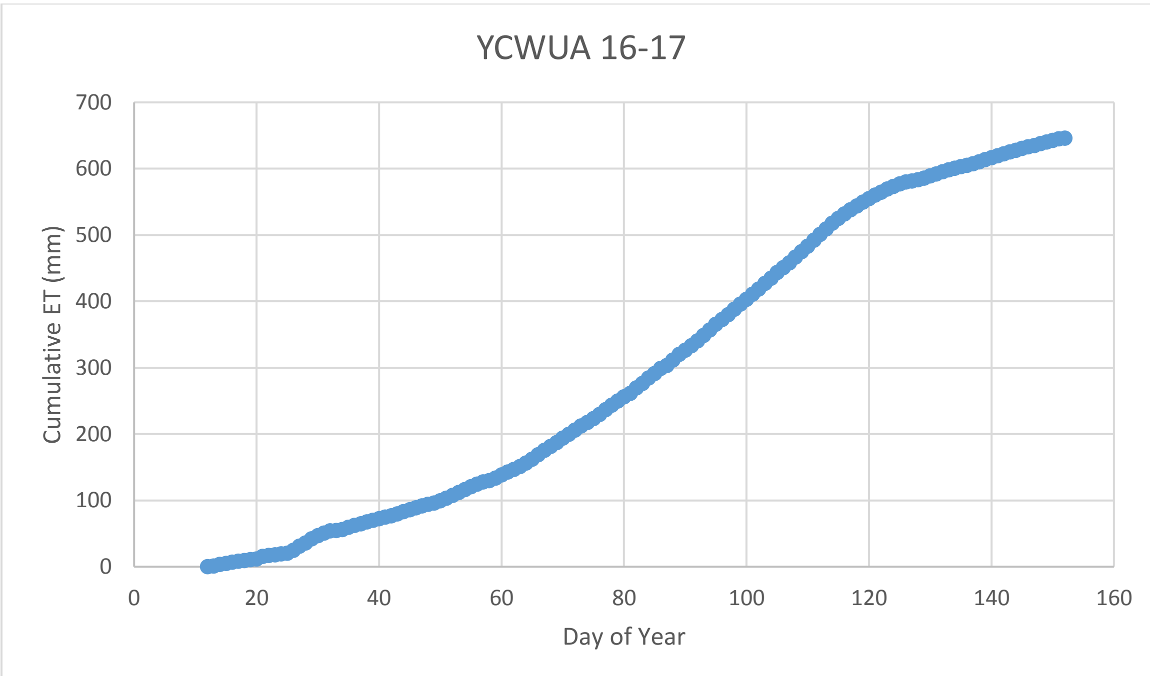


Figure 4: Estimates of daily ET (a) and cumulative seasonal ET (b) for wheat using Eddy Covariance methodology at the YCWUA site



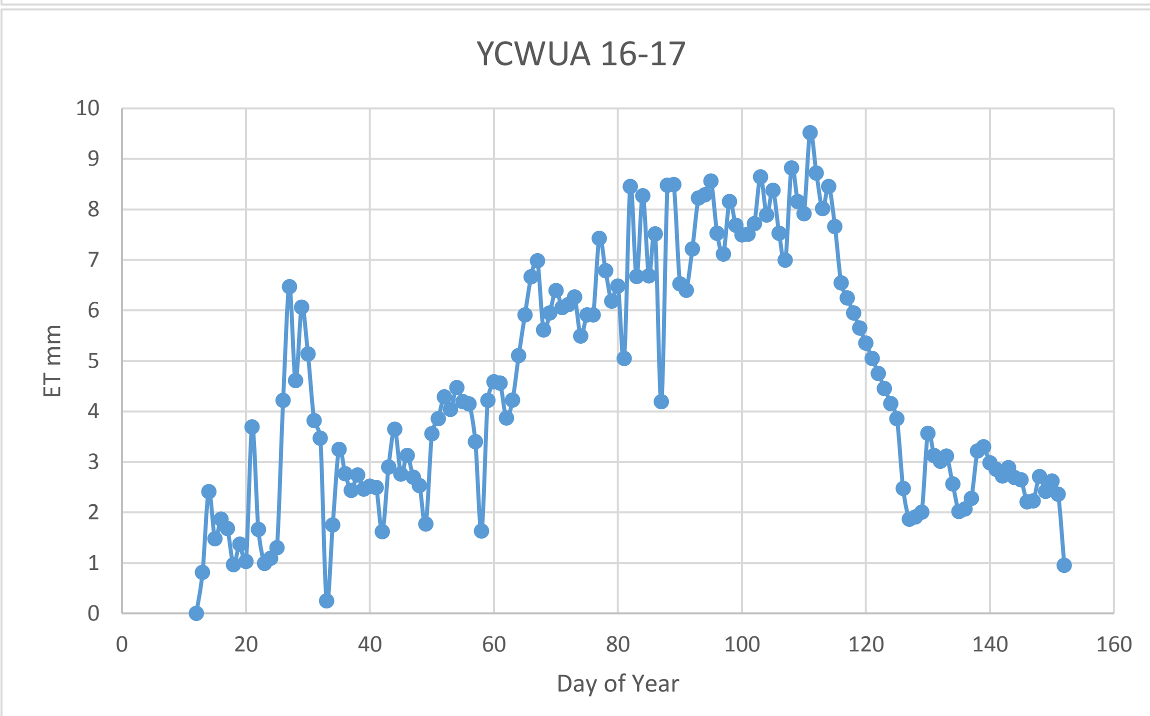


Figure 5: Total salinity (ECe) (a), the SAR (b), and soil Cl (c) across the seasonal cropping rotation for the YID site

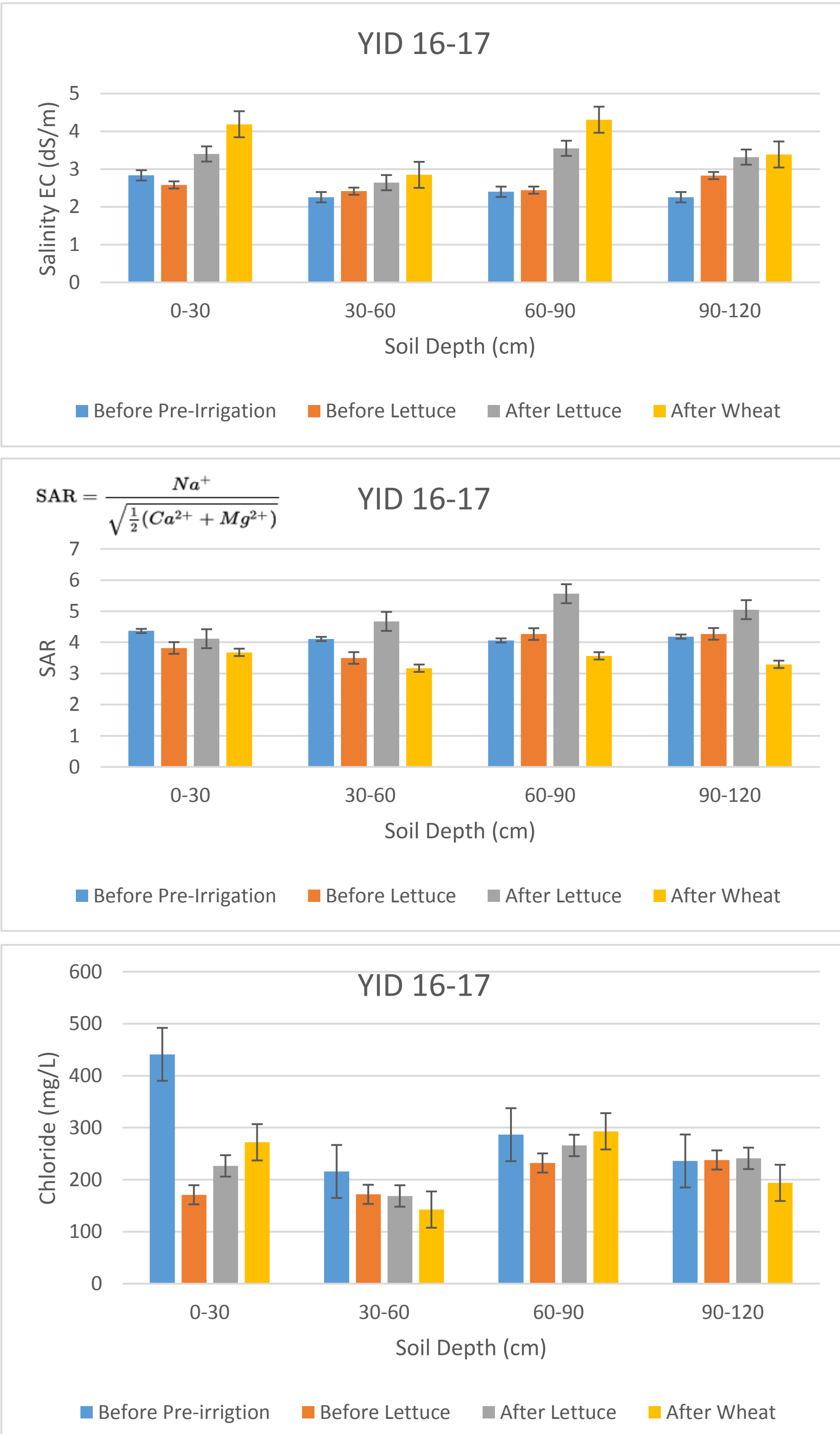
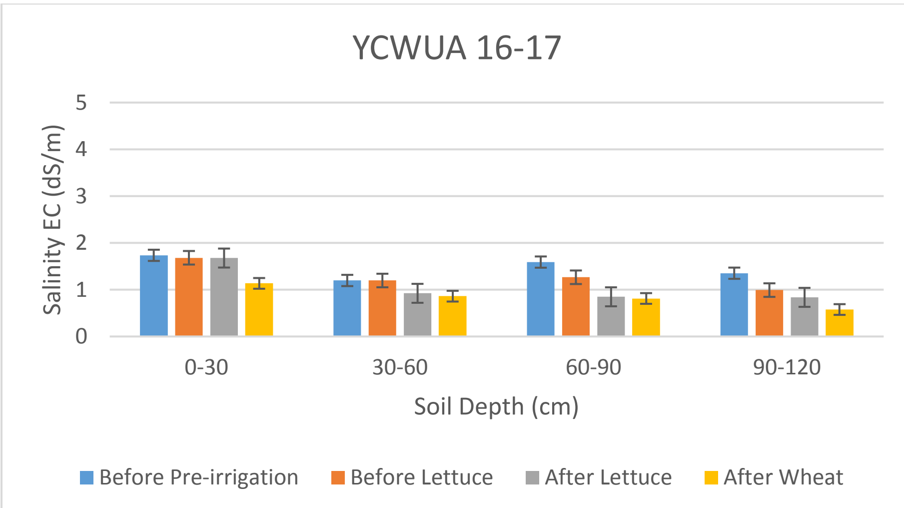
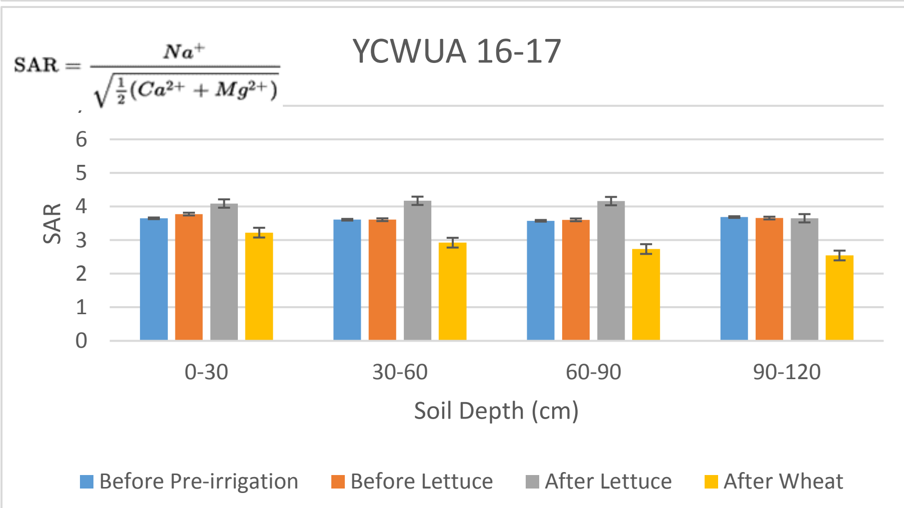


Figure 6: Total salinity (ECe) (a), the SAR (b), and soil Cl (c) across the seasonal cropping rotation for the YCWUA site





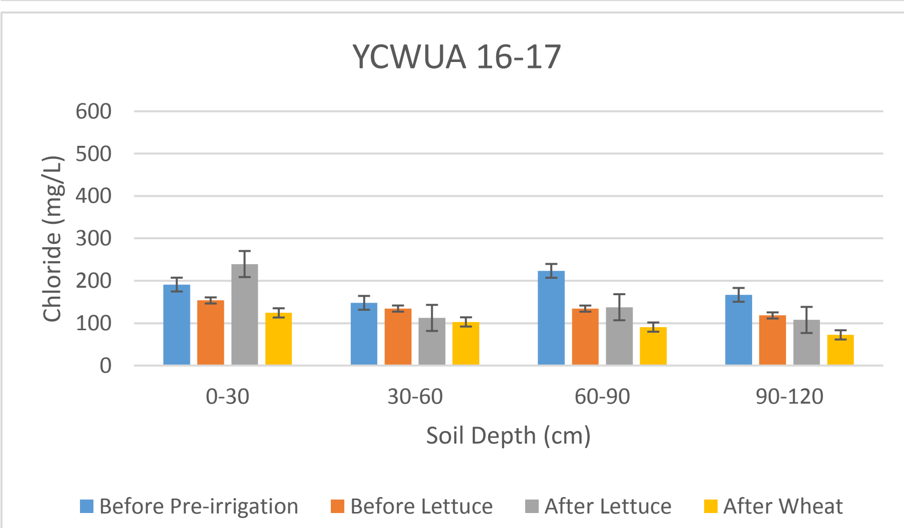
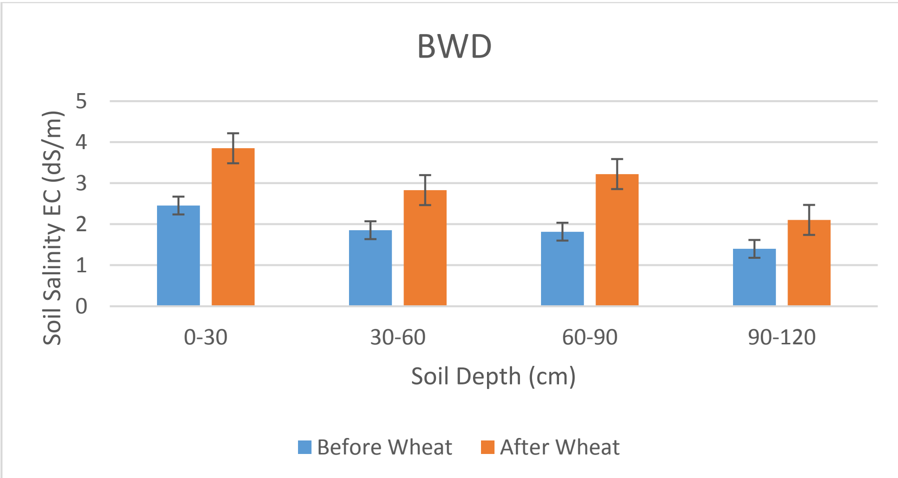
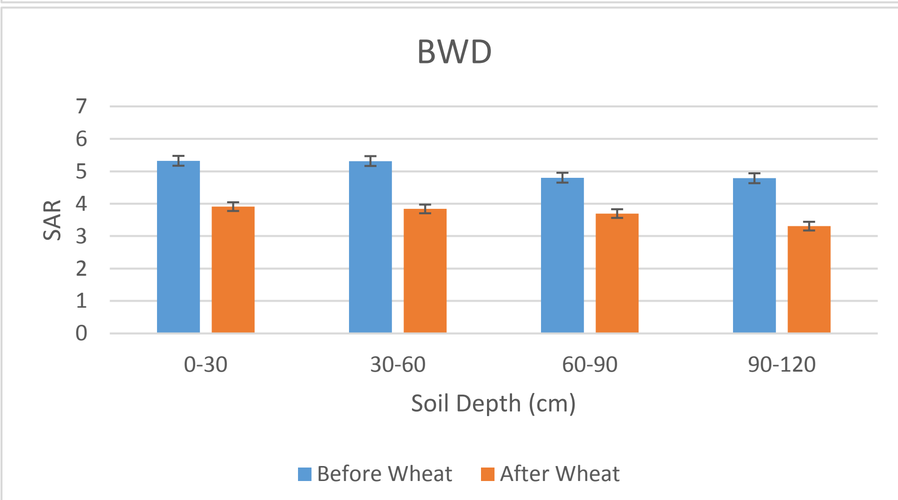
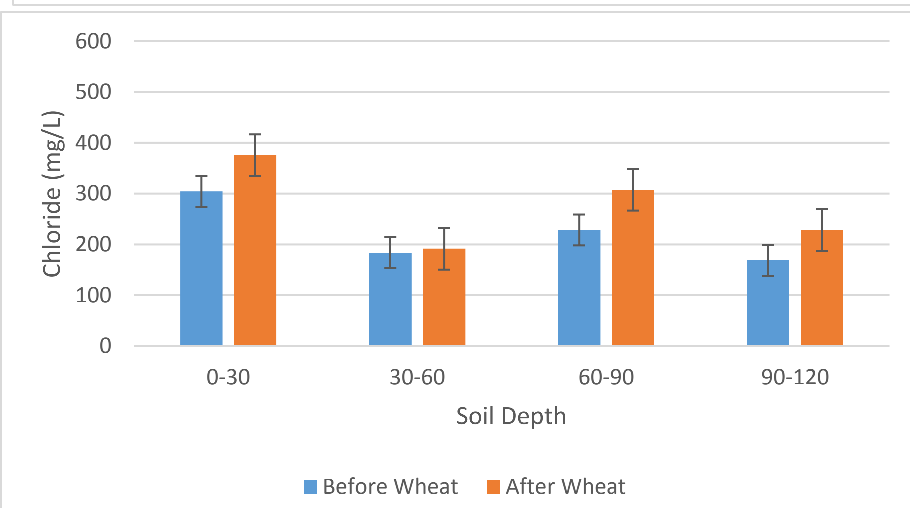


Figure 7: Total salinity (ECe) (a), the SAR (b), and soil Cl (c) before and after wheat at the BWD site







Tables

Table 1: Comparison of ions in irrigation water, saturation paste extract after wheat, and calculated concentration in soil water after wheat in surface soil for YID site

Ion	Irrigation Water (mg/L)	Saturation Paste Extract (mg/L	Soil Water (mg/L)
Ca	73	170	1778
Mg	28	36	388
K	5	34	393
Na	108	203	2137
Cl	109	272	3015
SO4	219	330	3358
CO3	140	1845	20,338

Concentration in soil water calculated from saturation percentage and soil moisture content at the time of sampling.

Table 2: Saturation Indices for selected mineral species in soil solutions

Mineral	Log IAP –Log Ks
Aragonite	3.798
Artinite	5.197
Brucite	2.443
Calcite	3.942
Dolomite (disordered)	7.284
Dolomite (ordered)	7.834
Epsomite	-3.520
Gypsum	-0.810
KCl	-4.270

Positive values for Log IAP-Log Ks indicate supersaturation

Table 3: Estimated leaching fraction during wheat production from three field sites

Site	Cl_{iw}/Cl_{sw} or LF
YID	0.09
YCWUA	0.20
BWD	0.08

Table 4: Estimated leaching fraction for pre-irrigation events from three field sites

Site	**Cl_{iw}/Cl_{sw} or LF**
YID	0.25
YCWUA	0.18
BWD	0.29